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Mars Terraforming: an Updated Review of available research

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Abstract

The basic initial stage of terraforming is ecopoiesis. In order to start ecopoiesis Mars needs to be changed to an pre-Cambrian like environment by increasing it's mean temperature, atmospheric mass, the availability of liquid water and decreasing the planets surface cosmic and UV radiation amount. Not all of those changes has to be done directly they can be induced by tele-connections and feedback effects, by changing one element a little an chain reaction can result changing the rest. The problems standing before such an Endeavour are the uncertainty about the availability and lability of CO_2 on the surface of Mars and whether it's sequestered in regolith or frozen in the poles. Also there is the problem of water on Mars, where they exist in what form and according to some models there is a question of their existence in any usable quantities. If Mars is found to be able to support terrafroming it can be achieved by three main means: spaceborne mirrors that will heat strategic parts of Mars, import of ammonia rich astroids to Mars and creation of halocarbon and perfluorocarbon substances on Mars.

Introduction

For many people involved in space exploration and related fields of study the obvious continuation of space exploration missions is the colonization of other planets. Although it may seem as an aspiration of the professional and enthusiast community, it may be that all of humanity needs to aspire to terraform Mars. In today's world with ever increasing population and pollution we may be reaching or even passing the limit of our planet to support us, although it is possible to manage the planets resources in order to maintain its ability to support our civilization indefinitely eventually we will want to expand. Although our planet is habitable and able to sustain our civilization at the moment it might not be the case in the future, therefore it would be a good survival strategy for us as a species to try to expand to other planets to increase our survival chances and to allow the human race a place to grow in the long run.

At the moment the best prospect for human colonization of other planets is Mars. Its environment is the most similar to earth and most of the elements needed for the first level of terraforming are already present on Mars, presumably locked beneath

the surface as sequestered CO^2 and frozen H^2O deposits. Also it is possible to perform planetary engineering on Mars with the technologies available to us today or in the near future.

Despite the understanding in the professional community that eventually we should establish a permanent presence on Mars the last review of the available research on the subject was done a little under a decade ago [McKay and Marinova, 2001], the purpose of this article will be to provide an review of the most recent available research on the subject of terraforming with emphasis on the stages preceding ecopoiesis.

Process and problems of terraforming

In order to be able convert the Martian environment to an environment capable of sustaining a basic ecosystem and small amount environmental modification will be required. This basic ecosystem stage of terraforming is called ecopoiesis [Haynes, 1990], Fogg [1998] defined ecopoiesis as "…the fabrication of an uncontained, anaerobic, biosphere on the surface of a sterile planet. As such, it can represent an end in itself or be the initial stage in a more lengthy process of terraforming."

In order to make Mars more hospitable for anaerobic life the Martian environment must be modified, according to Fogg [1998] four major modifications must be made:

1. Mean global temperature must be increased by ~60º K.
2. The mass of the atmosphere must be increased.
3. Liquid water must be made available
4. Surface UV and cosmic ray flux must be substantially reduced

these changes will turn Mars into a pre-Cambrian like environment capable of supporting anaerobic life based ecosystem. Although it may seem that performing all those changes on a planetary scale is an impossible task not all changes have to be caused directly, due to climactic feedbacks one action that is done can cause an chain reaction of events that will change the Martian environment. For example, increasing the mass of the atmosphere improves its function as a radiation and meteor shield; enhances the greenhouse effect, hence raising surface temperature; and widens the stability field of liquid water [Fogg, 1998]. Also by exploiting feedbacks and tele-

connections inherit to Mars mean that not every Kg of atmosphere added to the planet and degree of temperature will have to be added by direct action, only a relatively small action would be required to induce environmental change and eventually result in a semi stable environmental conditions.

The amount of time cited for these processes is between 20 and 50 years [Zubrin and McKay, 1993] from beginning of terraforming program execution. After this time it is possible to continue the terraforming process in order to produce an aerobic ecosystem in an earth like environment, however this process will take much longer, a baseline time scale for this process of ecosynthesis around 1000 years [Zubrin and McKay, 1993; Graham, 2004].

Most models assume that Mars had in it's past a denser atmosphere composed mainly of carbon dioxide, and terraforming models try to recreate this palaeoenvironment. Most of the models suggested for Martian terraforming use the common theory of the scientific community that most of the Martian poles are composed of H_2O with a top frosting of CO_2; under these conditions it is doubtful that the Martian poles contain enough CO_2 to cause a substantial increase in atmospheric pressure to start a self sustaining greenhouse effect. [Fogg, 1998]

However it is possible that a substantial amount of CO_2 is present sequestered in the upper kilometer of the Martian regolith [Fogg, 1998]. Computer models based on this theory had been done by Zubrin and McKay [1993] it shows that if the regolith carbon dioxide is distributed evenly over Mars it has to be bound very loosely to the regolith in order to facilitate a runaway greenhouse effect. However for polar regolith containing the equivalent of 1 bar CO_2 the effect works better.

A more recent model of Martian surface and atmosphere done by Hoffman [2000] indicates that the ancient Martian environment was not denser and warmer but was colder and thinner, with the main mass of liquid (and ice) is CO_2 and not H_2O. This CO_2 has evaporated over time and produced the current Martian environment.

This leads to the problem of water on Mars. Although Mars has reserves of water ice in the polar regions [Boynton et al., 2002] it is difficult to make this available to the biosphere due to the slow process of conducting heat through regolith, which would slow down greatly the process of melting the Martian permafrost [Fogg, 1998]. Although an model of the Martian hydrological cycle by Clifford [1993]

suggested that the lowest regions on Mars might be underlain by aquifers under artesian pressure more recent research by Cabrol and Grin [2001] indicates that currently Mars is a hydrologically dormant planet, in order to have liquid water under current day Martian environment the orbit of Mars has to be different, specifically a much higher obliquity.

The last two problems may seem trivial and even insignificant but they are important enough to mention. The first is the problem of Martian gravity since the purpose of terraforming Mars would be to establish a permanent human present on Mars it is important to know if it is possible to operate in Martian gravity for prolonged periods of time, this is still a completely unknown factor. The second problem is an ethical problem; the basic question is do we have the right to fundamentally change an extra terrestrial environment for our (colonial) needs [Fogg, 2000].

Methods to achieve Martian terraforming

The three most promising methods for achieving planetary environmental change on Mars are: orbiting mirrors, import of ammonia rich object and introduction of artificial halocarbon gases into the environment. These methods could be used alone or as a synergetic combination [Zubrin and McKay, 1993]. All of those methods will be discussed in detail.

Orbiting mirrors are one possible solution for achieving heating of the Martian surface. Although space-based sunlight reflecting device capable of warming the entire planet is not technologically possible for the foreseeable future, a much more practical solution would be a smaller mirror capable of heating a limited area of the Martian surface by a few degrees. According to Zubrin and McKay [1993] by placing the mirror in a position to heat the southern Polar Regions thus evaporating the CO_2 reservoir present there. They calculated that a space-based mirror of 125 km is sufficient to achieve a heating in the polar regions of 5ºK, if the mirror is constructed from solar sail type aluminized Mylar it would be feasible to build such a mirror providing it is manufactured in orbit. In order to offset the light pressure produced by the sun on the mirror the mirror would have to be positioned at an altitude of 214,000

km where Martian gravity will offset the light pressure and keep the mirror stationary [Zubrin and McKay 1993].

The second option is moving ammonia rich asteroids. Since ammonia is a very powerful greenhouse gas it is perfect for the purpose of terraforming. It is possible that nature has stockpiled ammonia in asteroid size object on the outer limit of the solar system [Zubrin and McKay 1993]. One possible way to move such asteroids from the outer solar system to Mars is by way of a Uranus gravity assist. It would take a ΔV of only 0.3 km/s with travel time of between 25 to 50 years. Assuming an asteroid of 10 billion tones orbiting the sun at a distance of 12 AU with a spherical diameter of 2.6 km to be sent to Mars via Saturn gravity assist would require ΔV of 0.3 km/s. A quarter of 5000 MW nuclear thermal fusion or fission based rocket that heats up some of the asteroids ammonia as fuel can produce an exhaust velocity of 4 km/s which would allow to move the asteroid to it's required course by using only 8% of the asteroids material. This approach will require ten years of steady thrust followed by 20 year coast to impact. The energy released by an impact of such an object will be around 10 TW-years, enough to raise the temperature of Mars by about 3ºC and provide an substantial shield against incoming UV radiation. Further effectiveness of such missions could be achieved by targeting the impacts at beds of nitrate. Assuming one such mission launched every year in about 50 years most of Mars will have an temperate climate and enough water will be melted to cover quarter of the planet 1m deep [Zubrin and McKay, 1993]. Although such approach to terraforming is purely speculative due to the lack of information on the occurrence of such ammonia rich asteroids.

The third approach is the production of halocarbons on Mars. In order to achieve, for example, a 5ºK induced heating the power required is about 1315 MW_e, just for comparison an average nuclear power plant produces about 1000 MW_e [Zubrin and McKay, 1993]. This undertaking will need a substantial economical support and a permanently staffed facility on Mars. Using such methods Mars could be transformed to a warm and slightly moist environment in a matter of several decades [Zubrin and McKay, 1993]. However there is a problem with halocarbon gases since Mars doesn't have an ozone layer the UV radiation will break the C-Cl bonds of the gases and thus reducing their residence from years to hours [Fogg, 1998].

A solution to this problem might be found in perfluorocarbon substances which are so inert that they can withstand the Martian radiation conditions much better [Fogg, 1998]. Additionally these substances absorb most of their radiation in the 5-16 μm range which is the perfect range to induce a greenhouse effect [Acerboni et al., 2001; Shine et al., 2005].

Conclusions

It is obvious that we have a large amount of knowledge about Mars but despite all that knowledge when we approach the task of planning it's terraforming we still rely to a large amount on educated guesses, we still don’t have an clear picture of the availability of in situ liquid water, the existence and dispersion of nitrate and an exact evaluation of the amount of CO_2 its location on the planet and it's lability. All of this research can be done only after we send a manned expedition to Mars, since even the best designed executed and complex robotic missions can do only so much. The only conclusion from this article is that of we are to terraform Mars by any amount we need to start with manned exploration of Mars, in order to conduct detailed studies into relevant subjects.

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